dr hab. inż., prof. ATH Wacław Brachaczek[1], mgr inż. Adam Chleboś[2]

1- **Akademia Techniczno-Humanistyczna w Bielsku-Białej,**
nr ORCID: 0000-0002-4782-8409
2- **Interdyscyplinarna Szkoła Doktorska ATH w Bielsku-Białej,**
nr ORCID: 0000-0003-3429-8098

Badania nad możliwością zastosowania włókien odpadowych i z recyklingu w płytach cementowych i gipsowych

Research on the possibility of using waste and recycled fibers in cement and gypsum boards

Abstract

The article presents the results of research on the influence of waste fibers from the tanning and textile industries on the flexural strength of cement and gypsum mortars in terms of their use for the production of facade boards. Waste fibers were used for the research consisting of two types of out-of-species wool fibers, which were waste from sheepskins and in the form of shears, aramid fibers in the form of a jersey from the utilization of bulletproof vests, fibers in the form of a jersey from the recycling of textile waste, and polyester fibers produced in the recycling process of PET bottles. The tests were carried out on samples of mortars containing cement and gypsum with dimensions of 12 x 75 x 150 mm. Waste fibers in cement-containing composites had a greater impact on the improvement of strength properties. It was found that despite the significant diversification of fibers, their addition improved the flexural strength, which justifies their use in the production of building materials.

Keywords

waste fibers, wool fibers, cement mortars, gypsum mortars, flexural strength

The use of fibers of various origins allows for a significant modification of the properties of cement mortars. Fiber-cement prefabricates have been used in construction for many years. In order to improve their mechanical properties, mainly synthetic or glass fibers in dispersed form are used [1]. The idea behind dispersed reinforcement is to obtain a material with high flexural and tensile strength. Synthetic fibers are generally produced from petroleum-based polymers, which is associated with CO2 emissions. The use of recycled fibers is an ideal solution for saving energy and raw materials and limiting environmental losses. These include, among others, waste fibers from the fur and tanning industry, which have a particularly negative impact on the environment. In recent years, more and more attempts have been made to use wool in various forms in the construction industry, among others, for the purpose of soundproofing rooms and thermal insulation [2]. Wool is characterized by high flexibility, chemical resistance to acids, high vapor permeability, fire resistance and tear strength [2, 3, 4]. Many reports in the literature indicate good cooperation and adhesion of gypsum to sheep wool fibers [5]. Their addition improves the mechanical properties and thermal insulation of cement composites [6]. The article presents the results of research on the improvement of mechanical properties of cement and gypsum mortars with the use of wool, aramid, cotton and polyester waste fibers and elements made of them for building partitions. In the case of such products, mechanical properties, density, dimensional stability, health and safety aspects and flammability are very important. The necessary conditions for the proper functioning of the composite are the cooperation of selected fibers of waste origin with the cement and gypsum mortar and the placement of the reinforcing layer in the zone where tensile stresses occur [7].

Research methodology

Tannery wool, haircut wool, polyester fibers, which are a product of PET bottle recycling, were used for the tests, as well as a stock made of aramid fibers made in the process of disposal of bulletproof vests and a stock made of mixed fibers (wool, cotton and synthetic fibers). The choice of materials used resulted from their availability and the potentially beneficial influence of the physical properties of the composite. The difference between the two types of fibers was their cleanliness. The shearling wool fibers were unwashed; they contained on their surface remains of lanolin and natural wax, produced by the sebaceous glands of animals. The polyester fibers were recycled and untreated as well. The possibility of using these fibers as dispersed reinforcement for the reinforcement of mortars was tested in terms of their use for the production of facing boards. The influence of the addition of waste fibers on the three-point bending strength of cement and gypsum mortars was investigated. The tests were carried out on samples with dimensions of 12 x 75 x 150 mm. Their thickness resulted from the intention to use fibers for the production of boards of similar thickness, and the remaining dimensions from the technology of creating and testing samples.

CEM I 42.5 cement, standard sand with a grain size not exceeding 2 mm and water in mass proportions of 1:3:0.5 were used to prepare the cement samples. In order to obtain the same consistency of the mortars, a superplasticizer was used (the consistency was plastic, spread approx. 140 mm). The defibrated material was evenly and unidirectionally (along the longer edge of the bar) introduced into the mortars in the amount of 0.5% of the fresh mass. Building gypsum with calcium sulphate content >50% mixed with water in a proportion of 1:0.6 was used to prepare gypsum samples. In this case, the consistency was also controlled by the use of a superplasticizer derived from polycarboxylic acids. Due to the initial phase of research and the desire to obtain a universal material with the same physical properties, regardless of the direction of installation, it was decided to place the reinforcement in the middle of the sample thickness. The appropriate consistency and light weight of the fibers allowed them to sink almost perfectly in the middle of the sample thickness without the risk of falling towards the bottom of the mold. Half of the mortar was placed in the mold, it was leveled and its surface was evened, then the fibers were placed and the rest of the mortar was poured. For each series, 5 samples were made, which were seasoned for 28 days before the measurements in accordance with [8]. The test results were compared with reference samples containing no fibers. The characteristics of the fibers used to reinforce the mortars are summarized in Table 1. In order to explain the effect of the fibers on the change in the strength properties of mortars and taking into account the possible risk of the influence of cement alkalinity on the degradation of natural fibers [9], microscopic observations were carried out using the JEOL JSM-5500 LV scanning electron microscope.

Tab. 1. List of fibers used for reinforcement

Nr	Type of fiber	Fiber origin	Fibers description	Thickness
1	Tannery wool	waste resulting from the cutting of leather sheepskins	out-of-species fibers of various thickness and length	ok. 25 µm
2	Haircut wool	made during sheep shearing	out-of-species mountain wool, unwashed, grained, fibers of different thickness and length	ok. 47 µm
3	Polyester fibers	the raw material for the production of fibers created in the recycling of PET waste	fibers of different thickness, declared length by the manufacturer 64 mm	24-29 µm
4	Textile stock	created in the process of recycling, tearing textile waste	a mixture of wool, cotton and synthetic fibers, in an unknown proportion, of different thickness and length	depends on the type of the fiber 15-30 µm
5	Aramid stock	fibers obtained in the process of recycling expired bulletproof vests	fibers of various lengths, no purchase possible on an industrial scale	11 µm

Test results

The averaged results of the bending strength measurements are presented in Table 2.

Tab. 2. Summary of the results of the bending strength of cement and gypsum fiber-reinforced samples

type of sample	type of fiber	sample density [kg/m^3]	flexural strength [MPa]
fibers in cement mortar	reference sample without fibers	1454	4,01
	tanning wool	1309	4,70
	haircut wool	1383	4,61
	polyester fibers	1388	5,61
	textile stock	1465	5,08
	aramid stock	1565	5,01
fibers in gypsum mortar	reference sample without fibers	1110	4,06
	tanning wool	1119	4,67
	haircut wool	1001	2,84
	polyester fibers	1014	3,76
	textile stock	1002	3,92
	aramid stock	1104	2,50

Polyester fibers had the greatest influence on the bending strength of cement mortars. Compared with the reference samples, the strength increased by more than 40%. In the case of wool tannery and haircut wool fibers, the effect on strength was similar, and the bending strength increased by approx. 15%. The addition of textile and aramid stock had no effect in a significant way to change endurance. In the case of gypsum samples, the addition of tannery wool fibers increased the bending strength by 15% compared to the reference sample. The remaining fibers reduced the strength of the samples.

The microscopic analysis shows that the tannery and haircut wool fibers were not degraded in the cement environment (fig. 1 and 2). The scaly structure of wool fibers was not degraded in the basis of cement samples. The products of hydration adhered well to the porous microstructure of both types of fibers. The tannery wool fibers also adhered to the mortar well plaster, which would explain their beneficial effect on bending strength. Wool fibers from haircut had a much worse connection with it (fig. 2c). In this case, voids are visible around the individual fibers, which was not noticed in the cement samples. The lower adhesion of woolen haircut fibers may be related to their insufficient purity. The residues of fats and waxes could have had a greater effect on reducing the adhesion of the fibers to the gypsum plaster.

Fig. 3 shows the microstructure of loose polyester fibers and fibers embedded in mortars. Unlike woolen fibers, they are smooth. Small impurities are visible on the surface of the loose fibers (fig. 3a). While these fibers adhere well to the cement mortar, gaps were visible between the mortar and the fiber in the case of gypsum, which may have a negative effect on the bending strength. The addition of these fibers had the greatest impact on improving the strength of cement samples.

Fig. 4 shows smooth aramid fibers from the stockpile. In this case, small gaps are also visible around the fibers in gypsum composites, which indicates a poor cooperation of the gypsum mortar with the fibers. The greater effect of the addition of aramid fibers on strength in cement composites may be related to the presence of well-adhering hydration products to the fiber surface, which was not observed in the case of gypsum samples.

The fibers in the textile stock, which are a mixture of wool, cotton and synthetics, are of poor quality. Fig. 5a shows clear mechanical damage to the cotton fibers, with a large number of cracks and splits. Similar damage was found on woolen fibers. The addition of these fibers improves the strength to a greater extent in the case of cement composites. Due to the fact that the composition of individual fibers is random (no repeatability of the stocking) and due to the different quality of the fibers and small impurities present in the stock, it is difficult to explain their influence on the change in the strength of composites.

Results analysis

The most beneficial effect on the strength of cement composites was noted in the case of homogeneous polyester fibers obtained in the PET bottle recycling process. The obtained test results indicate that woolly waste and shearing waste, which is difficult to utilize, can be used in the production of construction semi-finished products containing cement without the need for any chemical treatment. The pretreatment of such fibers would require a mechanical treatment involving defibering. Particularly promising are the results of the research with wool fibers being a waste wood. Contrary to haircut wool, decaying wool is definitely cleaner, with less grease and waxes. Therefore, their addition had a positive effect on the strength of cement and gypsum mortars.

In the case of gypsum composites, only the use of tannery wool brought the expected improvement in bending strength. It was very similar to the effect obtained in the cement composite and amounted to approx. 15%. In the microscopic photos, the tannery wool fibers were most regularly covered with gypsum crystallization products.

The cooperation of raw, chemically untreated waste fibers with gypsum mortar is much worse than with cement mortar. Artificial fibers with a smooth surface showed little adhesion with gypsum mortar. It can be concluded that the presence of such fibers in gypsum composites either had little effect on strength (polyester fibers and textile stock), or that the fibers had an effect in the mortar in a similar way to air pores. Particularly unfavorable influence was observed in the case of aramid stock and haircut wool. The effect of fiber cleanliness seems to have a greater influence in the case of cooperation with gypsum mortar than in the case of cement mortar. This is particularly evident in the case of wool fibers.

Fibers included in the textile mixture are characterized by a considerable variety in terms of the type and degree of damage. This makes it impossible to draw unequivocal conclusions regarding the influence of the fiber on the bending strength. The waste fibers affect the workability of the mortars due to their high absorbency. Therefore, in order to maintain consistency, it is necessary to use admixtures to improve flow. An important feature of cement and gypsum composites that changes as a result of adding fibers is, in addition to strength, density, which resulted mainly from different fiber density. It seems reasonable to investigate the influence of the type and quantity of waste fibers on the change of the thermal conductivity coefficient and the noise suppression coefficient of these composites.

Conclusions

Good cooperation of waste fibers with cement mortar allows you to realistically think about using them in construction. Tannery fibers proved to be the most versatile - only they improved the physical properties of both cement and gypsum composites. A more effective influence of waste fibers on changing the properties of cement and gypsum composites can be found in the initial chemical treatment, consisting in the removal of substances reducing adhesion.

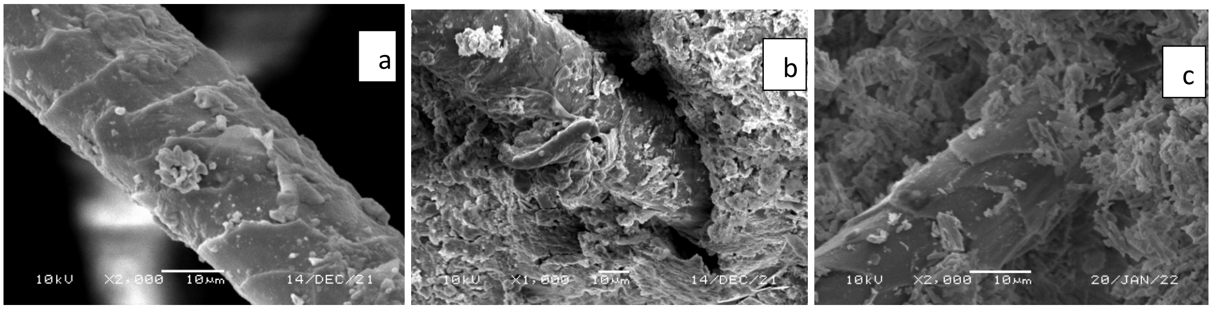

Fig. 1. Microscopic photo of tanning wool fibers before testing (a) and in a cement mortar (b) and gypsum mortar (c)

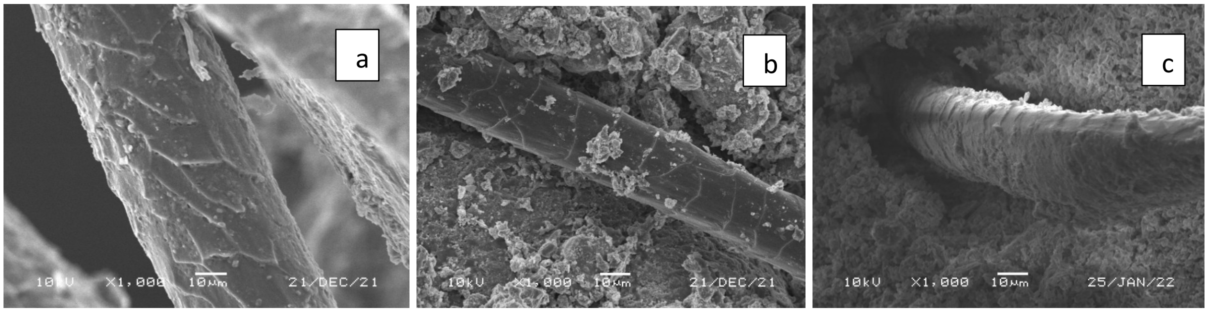

Fig. 2. Microscopic photo of wool fibers from haircut before testing (a) and in a cement mortar (b) and gypsum mortar (c)

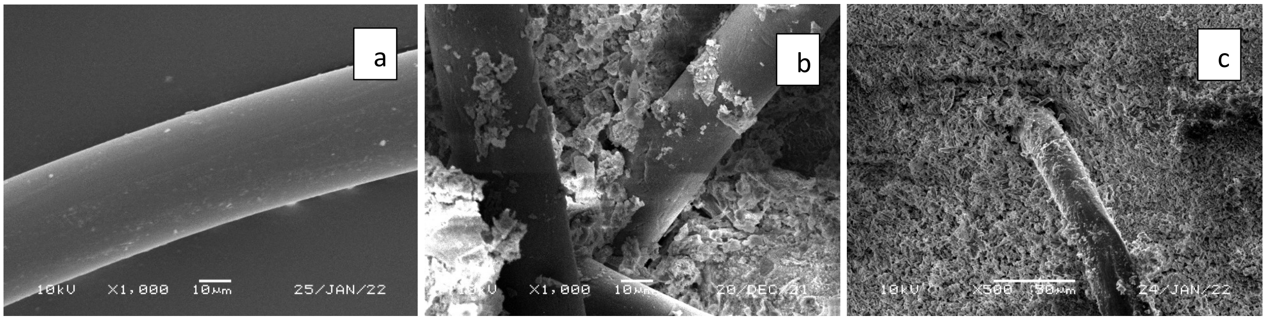

Fig. 3. Microscopic photo of polyester fibers before testing (a) and in a cement mortar (b) and gypsum mortar (c)

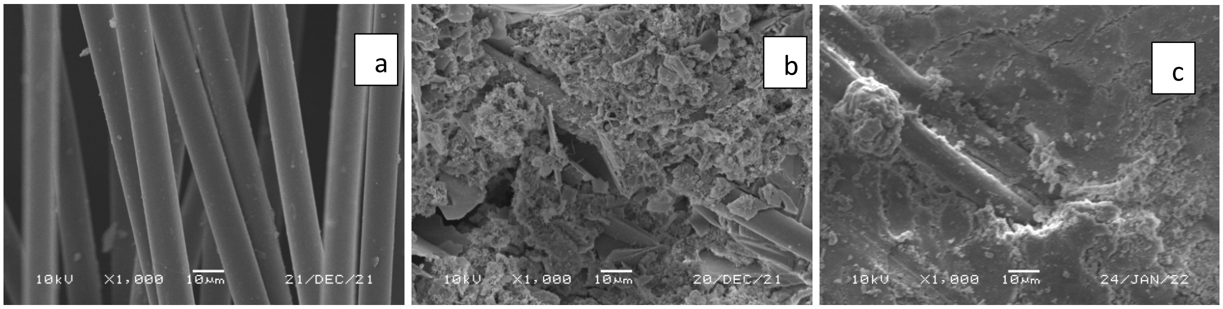

Fig. 4. Microscopic photo of aramid stock before testing (a) and in a cement mortar (b) and gypsum mortar (c)

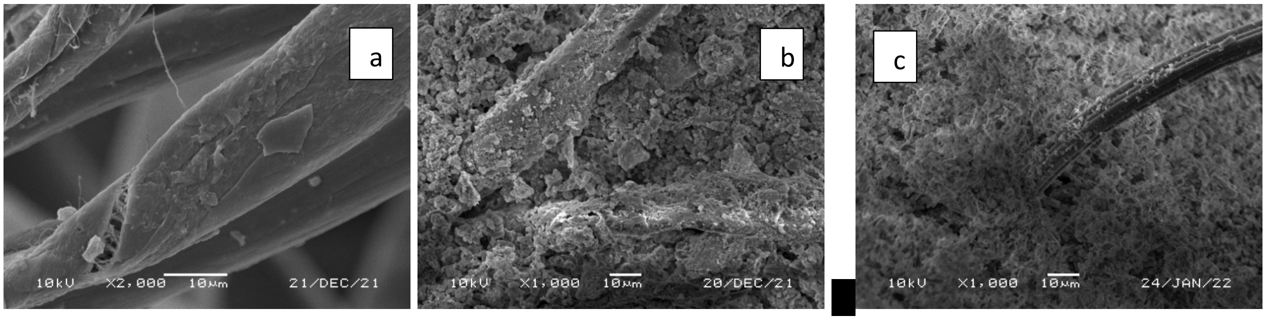

Fig. 5. Microscopic photo of the textile stock before testing (a) and in a cement mortar (b) and gypsum mortar (c)

Bibliography

[1] Schabowicz K., T. Gorzelańczyk. 2015. „Płyty włókno-cementowe jako okładziny wewnętrzne". *Izolacje* 20.5: 42 – 44.

[2] Cholewińska Paulina, et al. 2018. „Badanie impedancji, ciepłochronności i naprężenia zrywającego wełny jednolitej i mieszanej". *Wiadomości Zootechniczne* 56.2: 62 – 67.

[3] Molik E., A. Potocka. 2019. „Wybrane zagadnienia związane z możliwością wykorzystania wełny owczej". *Przegląd Hodowlany* 87.3: 31 – 33.

[4] Wasilewska A. W., B. L. Pietruszka. 2017. „Materiały naturalne w ekobudownictwie". *Przegląd Budowlany* 88.10: 50 – 53.

[5] Fantilli Alessandro P., Daria Jóźwiak-Niedźwiedzka, Piotr Denis. 2021. „Bio-Fibres as a Reinforcement of Gypsum Composites". *Materials* 14.17: 4830.

[6] CardinaleTiziana, et al. 2017. „Investigations on thermal and mechanical properties of cement mortar with reed and straw fibers". *International Journal of Heat and Technology* 35. S1: S375 – S382.

[7] Orlowsky Jeanette, Michael Raupach. „Beton zbrojony tkaniną – od badań do zastosowania Textile reinforced concrete – from research to application”. *Cement, wapno, beton* R. 16/78 6: 323 – 331.
[8] PN-EN 196-1:2005 Metody badania cementu – Część 1: Oznaczanie wytrzymałości.
[9] Fantilli Alessandro P., Daria Jóźwiak-Niedźwiedzka. 2021. „Influence of Portland cement alkalinity on wool-reinforcedmortar”. *Proceedings of the Institution of Civil Engineers-Construction Materials* 174.3: 172 – 181.
[10] Cardinale Tiziana, et al. 2017. „Investigations on thermal and mechanical properties of cement mortar with reed and straw fibers”. *International Journal ofHeat and Technology* 35. S1: 375 – 382.
[11] Jóźwiak-Niedźwiedzka Daria,Alessandro P. Fantilli. 2020. „Wool-reinforced cement based composites”. *Materials* 13.16: 3590.
[12] Rajabinejad Hossein, Ingrid-Ioana Bucişcanu, Stelian Sergiu Maier. 2019. „Current approaches for raw wool waste management and unconventional valorization: a review”. *Environmental Engineering & Management Journal* (EEMJ) 18.7: 1439 – 1456.